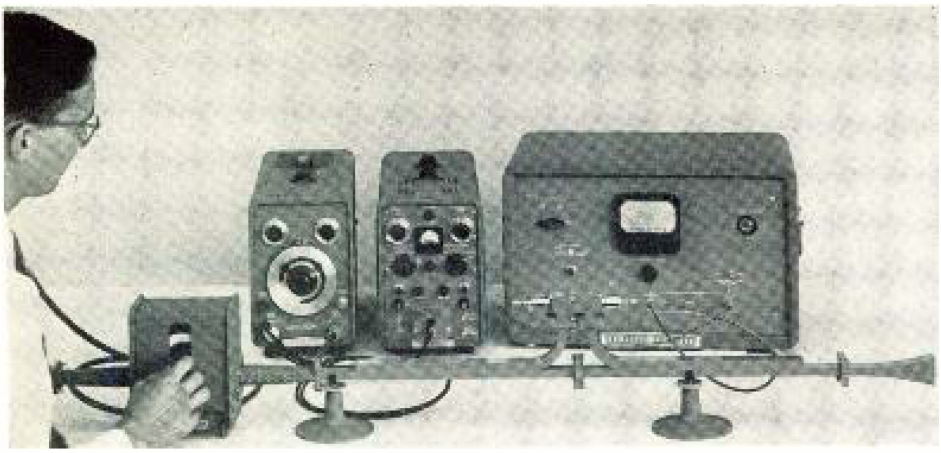


Fig. 1: Reflectometer system contains oscillator, 2 directional couplers, 2 detectors, a ratio meter, and a means of visual data presentation.

By N. L. PAPPAS

Measuring Microwave Impedance

N. L. Pappas

THE measurement of impedance at microwave frequencies has been made primarily by slotted line techniques up to the present time. A load (impedance) on the end of a r-f line whose value differs from the characteristic impedance of the line does not absorb all of the power incident upon it. This means that some of the power is reflected back towards the source. Therefore there is a set of incident and reflected waves in the transmission system. The summation of these waves establishes a standing wave which is measured with the use of slotted lines. The ratio of the reflected to the incident wave is also related to the impedance. The desired separation of the reflected and incident waves, and the formation of the ratio, is accomplished by a microwave reflectometer system. The measurement of impedance by this method is not an everyday experience, not for lack of motivation to use this more fundamental approach, but because of the lack of practical equipment. This lack of practical equipment has been eliminated by recent developments.

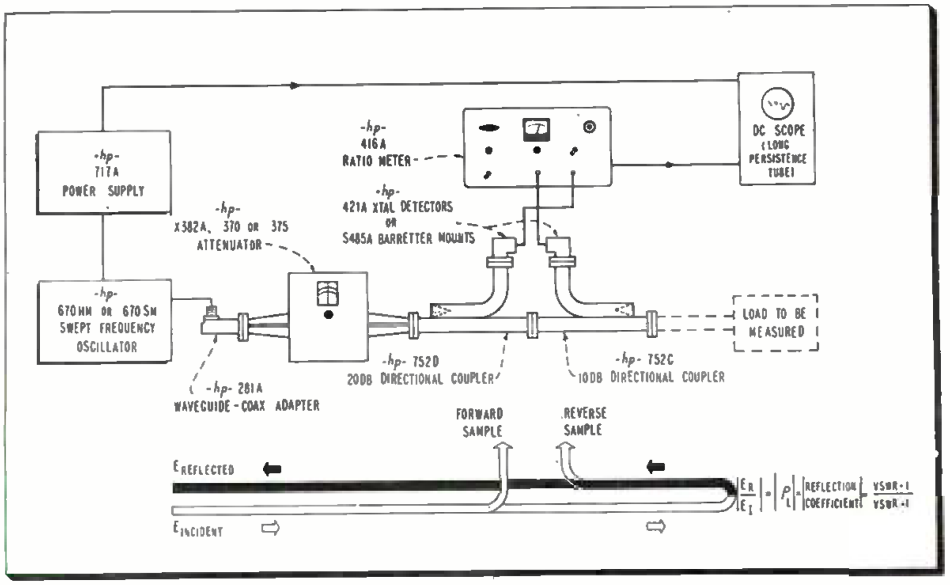
A reflectometer permits measurement of the magnitude of the reflection coefficient over bandwidths limited only by the bandwidths of its components. The system presents the data as a continuous function of frequency. For example, this feature makes the investigation of resonances a simple task. The use of a swept frequency oscillator permits rapid assimilation of data as a function of frequency. The data may be presented on an oscilloscope, or recorded. The accuracy of the system is as good, if not better, than the best of slotted lines. Such a reflectometer is now a reality.

Principle of Operation

The reflectometer basically performs two functions; the separation of incident and reflected waves, and the formation of the ratio of the reflected to the incident waves. A reflectometer system may contain an oscillator, two directional couplers, two detectors, a ratio-meter and a means of visual data presentation. The components are assembled as shown in Figs. 1 and 2.

The modulated r-f power leaves the oscillator and propagates down the line towards the load. The first (incident) directional coupler has the property of sampling power in the main line and hence some of the incident power enters the secondary arm, subsequently reaching the first square law (incident) detector. The square law detector characteristic is not necessary for this system. Practical linear detectors, though desirable, are not available at microwave frequencies. The detector output is a voltage at the modulation frequency which has an amplitude proportional to the incident r-f power. The incident power passes the second (reflected) coupler and the sampled power is absorbed by

Fig. 2: Block diagram showing component arrangement of microwave reflectometer


-hp- 717A POWER SUPPLY
-hp- 416A RATIO METER
DC SCOPE (LONG PERSISTENCE TUBE)
-hp- 421A XTAL DETECTORS OR 8485A BARRETTER MOUNTS
-hp- X382A, 370 OR 375 ATTENUATOR
-hp- 670H OR 670SM SWEPT FREQUENCY OSCILLATOR
LOAD TO BE MEASURED
-hp- 281A WAVEGUIDE-COAX ADAPTER
-hp- 752D 20DB DIRECTIONAL COUPLER
-hp- 752C 10DB DIRECTIONAL COUPLER
FORWARD SAMPLE
REVERSE SAMPLE
E REFLECTED
E INCIDENT
REFLECTION COEFFICIENT
VSWR-1 VSWR+1

N. L. PAPPAS, Consulting Engineer, 25981 Vinedo Lane, Los Altos, Calif. (Formerly with the Hewlett-Packard Co., Palo Alto, Calif.)

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Practical reflectometer permits rapid measurements of reflection coefficient of r-f lines by separation of incident and reflected waves and formation of their ratio. Bandwidth is limited only by bandwidth of its components. Sweep frequency oscillator permits rapid assimilation of data as a function of frequency

With the Reflectometer

the perfect load in the secondary arm. Assuming that the line load is not matched, some of the incident power is reflected back towards the source. The reflected power is sampled by the reflected coupler and the sample flows into the reflected square law detector. The detector output is a voltage at the modulation frequency. The amplitude of this voltage is proportional to the reflected power. The reflected power passes the first (reflected) coupler and the sampled power is absorbed by the perfect load in the secondary arm. Assuming that the source is not matched to the line, some of this power is reflected back into the line. This power is now considered as incident power. The ratio-meter forms the ratio of the two detectors' output voltages.

Requirements

The practical reflectometer should be able to measure reflections of magnitudes in a range from 0.01 (1.02 SWR) to 1.00 (infinite SWR). The measurement of 0.01 reflections implies that the couplers should have directivities greater than 40 db. In addition, sufficient r-f power should be available at the source in order to have a good signal to noise ratio in the reflected channel.

The measurement of 1.00 reflections (infinite SWR) requires that the reflected detector mismatch be small.

The range of reflections to be measured is 100:1. This means that the detector law be accurate over a 40 db input r-f power range.

Components

The existence of commercially available directional couplers, in which directivity is greater than 40 db, permits accurate separation of incident and reflected waves. This means, for example, that less than 1% of the incident power sampled by the reflected coupler enters the reflected detector (Fig. 7, path R_1). The coupling law of the couplers varies by less than 1 db over their 50% bandwidth. Even this variation is unimportant because it is the ratio of the reflected and incident coupler's samples that should be independent of frequency. This ratio varies by less than ½ db over the coupler's bandwidth.

The formation of a ratio at audio frequencies is, intuitively, more practical than an attempt to do this at microwave frequencies. Therefore the r-f source is modulated and subsequently demodulated by detectors. The detectors may be crystal detectors or barretters. These two types of detectors have almost a square law characteristic over the range of r-f powers occurring in practical systems. Practical detectors are available in which the square law characteristic varies by less than ± ½ db over a 40 db dynamic range. This is achieved by proper video loading of the crystals (Fig. 8). The detector's output signal to noise ratio is sufficient to permit measurement of the reflected channel output when very low reflections are being measured. The ratio of the rectification efficiencies of the two detectors is essentially independent of frequency as is shown in Fig. 4. The reflected detector mismatch (less than 1.5 SWR) is the source of the beats in the figure. Fig. 7, path R_3 illustrates this phenomenon.

The outputs of the two detectors are voltages at the modulation frequency which are in phase (1,000

(*Continued on page* 128)

METHOD OF MEASUREMENT	LOAD REFLECTION COEFFICIENT OR V S W R		
	$0<P_L<0.2$ $1<\sigma_L<1.5$	$0.2<P_L<0.5$ $1.5<\sigma_L<3$	$0.5<P_L$ $3<\sigma_1$
Slotted Section	1.02	1.02	1.02
Reflectometer Fixed Frequency Fixed Short	1.03	1.05	1.10
Reflectometer Fixed Frequency Sliding Short	1.02	1.04	1.07
Reflectometer Fixed Frequency Sliding Short, Sliding Load & SST	1.005	1.04	1.05

Fig. 3: Major cases, summarized in terms of residual SWR.

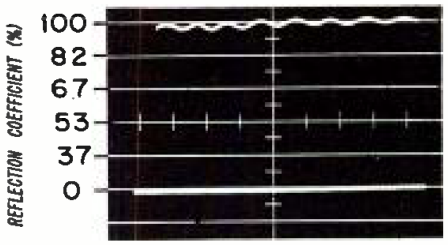


Fig. 4: Scope pattern obtained when calibrating reflectometer with a short (100% reflection)

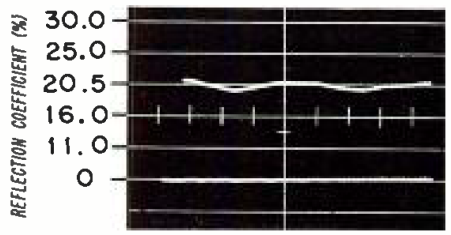
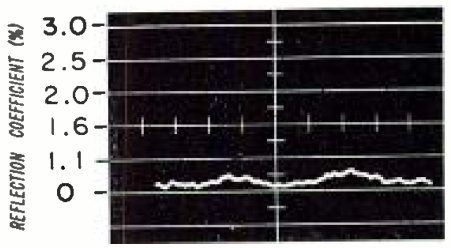


Fig. 5: Pattern obtained using Model X916E Series Standard Reflection of 20%

Fig. 6: Reflection of less than ½%. Spurious signals and detector mismatch cause fluctuations



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Reflectometer

(*Continued from page 73*)

cps in some practical systems). The ratio-meter forms the ratio of the reflected to incident voltages and a meter reading results. Also there is an output, for recording purposes, proportional to the meter deflection. The ratio-meter is designed to provide 100%, 30%, 10% and 3% full scale readings (with appropriate range switching). The ratio-meter's reading is independent of the source's output power variations encountered in practice. Specifically a range of 13 db is accommodated.

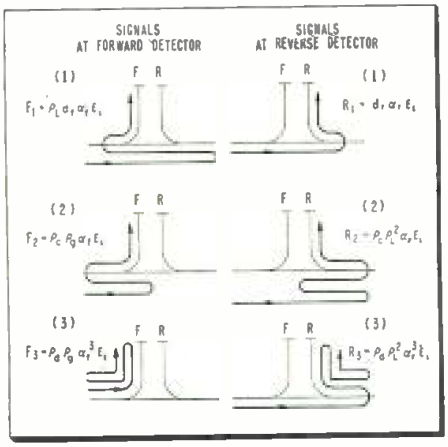

Fig. 7: Signal paths

Any source of modulated r-f power which has an output greater than 1 mw can be used. A sweep oscillator for use in reflectometer systems is available. Such an oscillator makes possible the use of the high speed data presentation abilities of the reflectometer. The sweep oscillator may be manually tuned. This feature is desirable when narrow band resonance phenomena are under investigation. An interesting point is that even if only manually tuned, the system can still provide data faster than existing impedance measuring systems.

Calibration and Errors

The practical system is calibrated by placing a short or other known reflection load on the end of the line. A short on the line should yield a 100% reading independent of frequency. The system errors give rise to deviation from 100% as frequency is varied. Fig. 4 illustrates this point over the frequency band 8.2 to 10 KMC. Note that the average reading is 100% and that a periodic ripple is present. This ripple is caused by mismatches in the system which give rise to spurious signals. The flatness of the trace's average (Fig. 4) at-

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tests to the independence of frequency of the ratio of the (crystal) detector's rectification efficiency. In this case, the reflected detector's mismatch is the main source of the ripples (R_2 of Fig. 7). F_2 of Fig. 7 is analogous to R_3 for it is due to the first detector and source mismatches. Improper flange alignment between the two couplers gives rise to spurious signals F_3 and R_3. The spurious signals that dominate at low load reflections arise from the imperfect coupler directivities (R_1 and F_1 of Fig. 7). A directivity greater than 40 db results in error signals equivalent to load reflections which are less than 1%. Therefore the system error can be 100% when a 1% load is measured, but proper interpretation of the data prevents this. The data resulting from a load whose reflection is less than ½% over the band are shown in Fig. 5. The fine structure is due to the spurious directivity signals and the large but slow variation is due to mismatches within the crystal detectors.

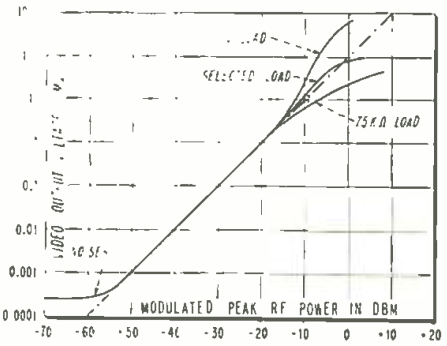

Fig. 8: Output under various loads

There are occasions when it is advantageous to calibrate at reflections other than 100%. A calibration line resulting from a standard 20% reflection is shown in Fig. 1. The ripples are smaller than in the 100% case because the spurious signal that dominates under these conditions is proportional to the load reflection.

The total system error can best be expressed as an equivalent SWR for purposes of comparison with slotted line systems. The residual SWR of a good slotted line is 1.02, independent of the magnitude of the reflection coefficient. The reflectometer residual SWR, on the other hand, is a function of the magnitude of the reflection coefficient. Fig. 3 summarizes the major cases.

Transistor Warning!

RETMA is warning its members that they should look carefully into the quality and operation of any silicon junction transistors that they plan to purchase abroad.

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